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FACTORS INFLUENCING THE NOISE EXPOSURE UNDER THE LANDING PATH FOR JET TRANSPORT AIRCRAFT

TECHNICAL REPORT



March 1965

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by

A. C. Pietrasanta

Bolt Beranek and Newman Inc.
15808 Wyandotte Street
Van Nuys, California 91406

Under Contract FA64WA-4949

for

FEDERAL AVIATION AGENCY

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ABSTRACT

On the basis of available acoustical data calculations have been made to determine the quantitative effect on the noise exposure under the landing path of changes in runway threshold location, glide slope angle, and engine power setting. Each of these factors has been examined independently, i.e. with all other conditions held constant, for operation of a turbofan-powered Convair 990 and a turbojet-powered Boeing 707-120. Changes in noise exposure are described in terms of changes in perceived noise level and/or changes in the area enclosed by equal perceived-noise-level contours for a range in glide slope angles from $2\frac{1}{2}^{\circ}$ to 5° , runway threshold displacements of 1000 feet and 2000 feet, and four different engine power settings from approximately 50% thrust downward. The results can be generalized to apply to essentially all four-engine commercial jet airliners in operation today. They provide the basis whereby changes in these factors can be evaluated in terms of their effectiveness in reducing noise exposure alone. Further, trading relationships among changes in these factors can be derived from the data.

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I. INTRODUCTION

The noise produced under the landing path by jet transport aircraft is influenced by several factors. These include aircraft type, engine type, engine power setting, glide slope angle, and the location of the runway threshold. Commercial jet aircraft in operation today are equipped with from two to four engines. For any given aircraft the noise levels under the approach path are directly related to the engine power settings and the aircraft altitude. The altitude is dependent on the glide slope path being employed and the location of the runway threshold, both of which vary from airport to airport. And, of course, the glide slope path being flown indirectly affects the engine power being used by the pilot.

Under Contract FA64WA-4949 we have conducted a study to determine quantitatively the effect of these factors on the noise produced under the landing path. We have performed detailed calculations for two four-engine jet aircraft, one with turbojet engines - the Boeing 707-120, and one with turbofan engines - the Convair 990. For each of these aircraft we have determined the relative changes in noise exposure for changes in engine power setting from approximately 60% maximum thrust downward, changes in glide slope angle from $2\frac{1}{2}^\circ$ to 6° , and displacement of the runway threshold up to 2000 ft.

The study was confined to available data in our files; no additional field measurements were conducted. The basic noise source data on which this report is based are given in Appendix A. Curves of perceived noise level-versus-distance for various engine power settings are presented for both the 707-120 and the 990.^{1,2,*} All data have been corrected for the latest procedure for calculating perceived noise level^{3/} and include corrections for air attenuation as prescribed by the SAE.^{4/}

The results of the study are presented in the following three sections of the report: Section II on the effect of glide slope angle, Section III on the effect of threshold displacement, and Section IV on the effect of

* Superscripts refer to references at the end of the report.

engine power setting. For each of these factors changes in perceived noise level have been determined for several locations directly under the landing path. These perceived noise level differences can be related to subjective reaction by remembering that a change of 6 PNdB represents a 50% change in noisiness, a change of 10 PNdB a 100% change in noisiness, and a change of 16 PNdB a 200% change in noisiness. Another method of comparison employed is to show changes in the size of the 100-PNdB noise contour. This has been done for changes in glide slope angle and engine power setting. In these instances the areas enclosed by the 100-PNdB contours, as well as the 105-PNdB and 110-PNdB contours, have also been calculated and compared.

No conclusions are drawn in this report concerning the wisdom or appropriateness of instituting changes in procedures based on the results of this study. Obviously many factors other than the change in noise exposure should be considered before any changes are contemplated. However, what this report does purport to do is to provide information whereby changes in any of the factors considered can be evaluated on the basis of their effectiveness in reducing noise exposure alone. More importantly, data are provided from which one can derive trading relationships among changes in the various factors.

II. THE EFFECT OF GLIDE SLOPE ANGLE

ILS approaches to most airports in the country result in aircraft flying a glide slope path with an angle of approximately $2\frac{1}{2}^{\circ}$ to 3° , depending on the obstruction clearance requirements at a particular airport. Since the ILS runway is often the active runway even during good weather, common practice among airline pilots is to fly an ILS approach even when visual reference is good. Practically speaking jet transport aircraft often attempt to fly at or above the ILS glide slope path. At some airports in the country, due to terrain conditions, approaches are made well above a glide slope angle of $2\frac{1}{2}^{\circ}$ to 3° . The higher the glide slope angle used during approach, the lower the noise levels on the ground underneath the landing path. This is due directly to the increased altitude and indirectly to the lower engine power that is often employed.

The effect on the noise exposure underneath the approach path for jet aircraft flying several different glide slope paths is examined in this section. We have chosen the range of glide slope angles from $2\frac{1}{2}^{\circ}$ to 6° . Landing profiles for several glide slope paths covering this range are shown in Fig. 1. In this analysis we have assumed that the engine power during approach is held constant regardless of the glide slope angle. Although this condition would probably not exist in practice, this assumption of fixed engine power has been made so that the effect of changes in the glide slope path can be examined independently. The noise heard on the ground is assumed to be influenced only by the change in altitude brought about by the different landing profiles.

Table I presents the perceived noise levels* directly underneath the landing path at one-mile intervals out

* Perceived noise level values presented throughout this report, either in tables or in the form of contours, represent the maximum perceived noise levels in PNdB that would be heard on the ground during an aircraft flyover.

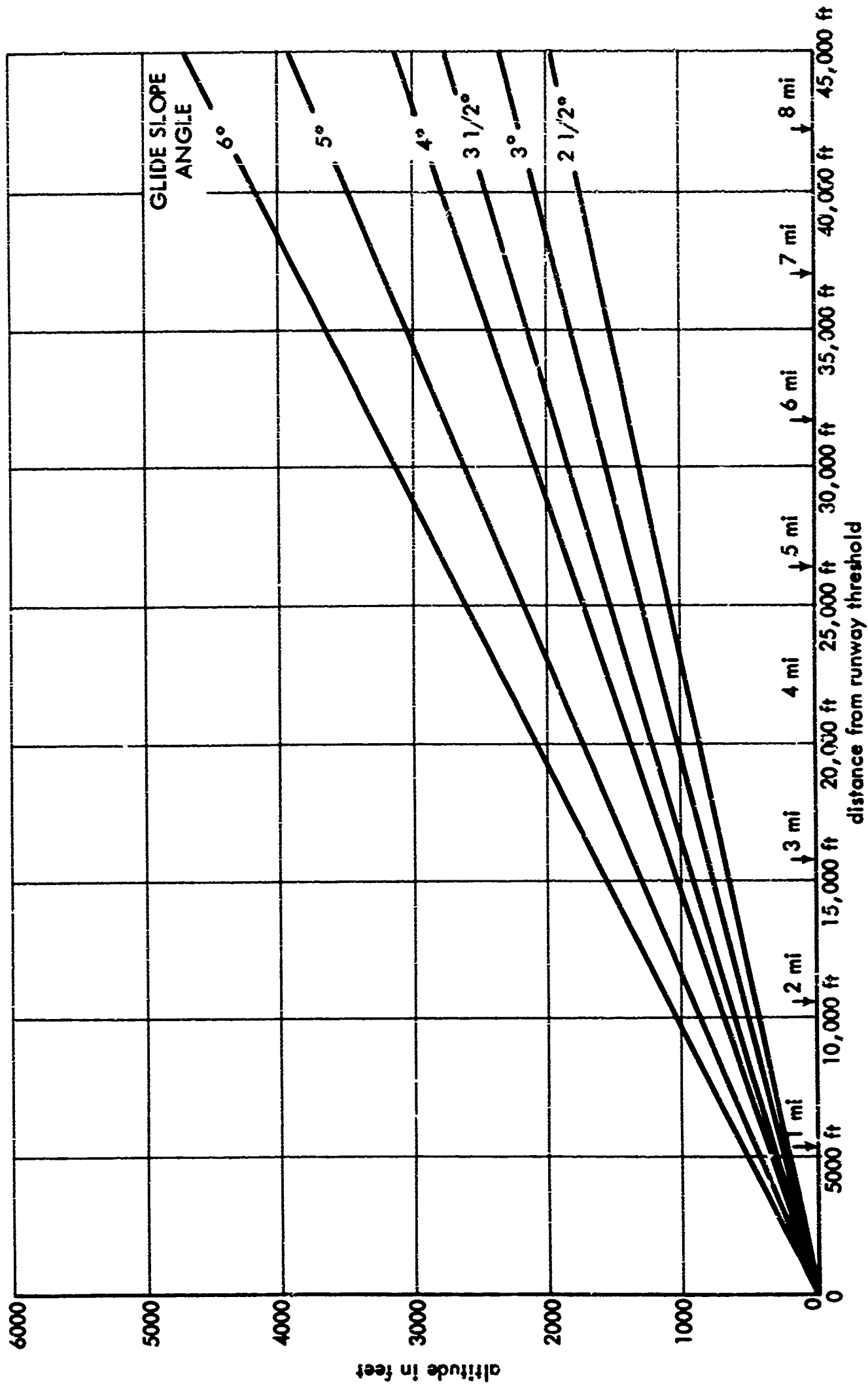


FIGURE 1. LANDING PROFILES FOR SEVERAL GLIDE SLOPE ANGLES FROM 2 1/2° TO 6°

to six miles from the end of the runway for a 990 flying various glide slope paths from $2-1/2^\circ$ to 5° . Values are given for two engine power settings, 2500 lbs per engine in Part A and 4000 lbs per engine in Part B. Similar data for the 707-120 are given in Table II, also for two engine power settings.*

Table I shows that the perceived noise levels at a point one mile from touchdown, for example, for a constant thrust of 2500 pounds per engine, vary from 118 PNdB for a $2-1/2^\circ$ glide slope to 108 PNdB for a 5° glide slope. This represents a total change of 10 PNdB. Farther out under the landing path the change in perceived noise level, for a change in angle from $2-1/2^\circ$ to 5° , increases until at the six-mile position the difference is 15 PNdB for either 2500 pounds thrust per engine or 4000 pounds thrust per engine.

For smaller changes in glide slope angle the change in perceived noise level is correspondingly smaller. The average change in perceived noise level at points under the approach path one to six miles from touchdown is 2 PNdB for a glide slope change from 3° to $3-1/2^\circ$. For a change from 3° to 4° the average change is about 4 PNdB. These average changes are the same for both engine settings.

For the 707-120 the data in Table II show about the same results. The change of perceived noise level at most positions directly underneath the landing path one mile to six miles from touchdown, for a change in glide slope from 3° to $3-1/2^\circ$, is also about 2 PNdB. For a change in glide slope from 3° to 4° , the difference in perceived

* For both the 990 and the 707-120 this report has considered the noise produced at four different engine settings ranging from approximately 60% thrust downward. (See Section IV and Appendix A.) In Tables I and II the variation in perceived noise level with glide slope angle has been presented for the two intermediate engine power settings for both aircraft.

TABLE I

EFFECT OF VARIOUS GLIDE SLOPE ANGLES ON THE PERCEIVED NOISE LEVELS DIRECTLY UNDER THE APPROACH PATH FOR A CONVAIR 990

A. Constant Power of 2500 lbs Thrust per Engine

Distance from Touchdown in Miles	Perceived Noise Levels in PNdB					
	2-1/2°	3°	3-1/2°	4°	5°	5°
1	118	116	115	113	110	108
2	110	108	106	104	101	99
3	105	103	101	98	95	92
4	101	98	95	94	91	88
5	98	95	93	91	87	84
6	95	92	90	88	84	80

B. Constant Power of 4000 lbs Thrust per Engine

Distance from Touchdown in Miles	Perceived Noise Levels in PNdB					
	2-1/2°	3°	3-1/2°	4°	5°	6°
1	122	120	119	117	115	112
2	115	112	110	108	105	103
3	109	107	105	102	99	96
4	105	102	100	98	94	91
5	102	99	97	94	91	87
6	99	95	94	91	88	84

TABLE II

EFFECT OF VARIOUS CLIDE SLOPE ANGLES ON THE PERCEIVED NOISE LEVELS DIRECTLY UNDER THE APPROACH PATH FOR A BOEING 707-120

A. Constant Power of 4500 lbs per Engine

Distance from Touchdown in Miles	Perceived Noise Levels in PNdB					
	2-1/2°	3°	3-1/2°	4°	5°	6°
1	122	120	119	117	115	113
2	115	113	111	109	106	104
3	110	108	106	104	101	98
4	106	104	102	100	97	94
5	103	101	98	97	93	91
6	101	98	96	94	91	88

B. Constant Power of 6000 lbs per Engine

Distance from Touchdown in Miles	Perceived Noise Levels in PNdB					
	2-1/2°	3°	3-1/2°	4°	5°	6°
1	125	124	122	121	118	116
2	118	116	115	113	110	108
3	114	111	110	108	105	102
4	110	108	106	104	101	98
5	107	105	103	101	98	95
6	105	102	100	98	95	93

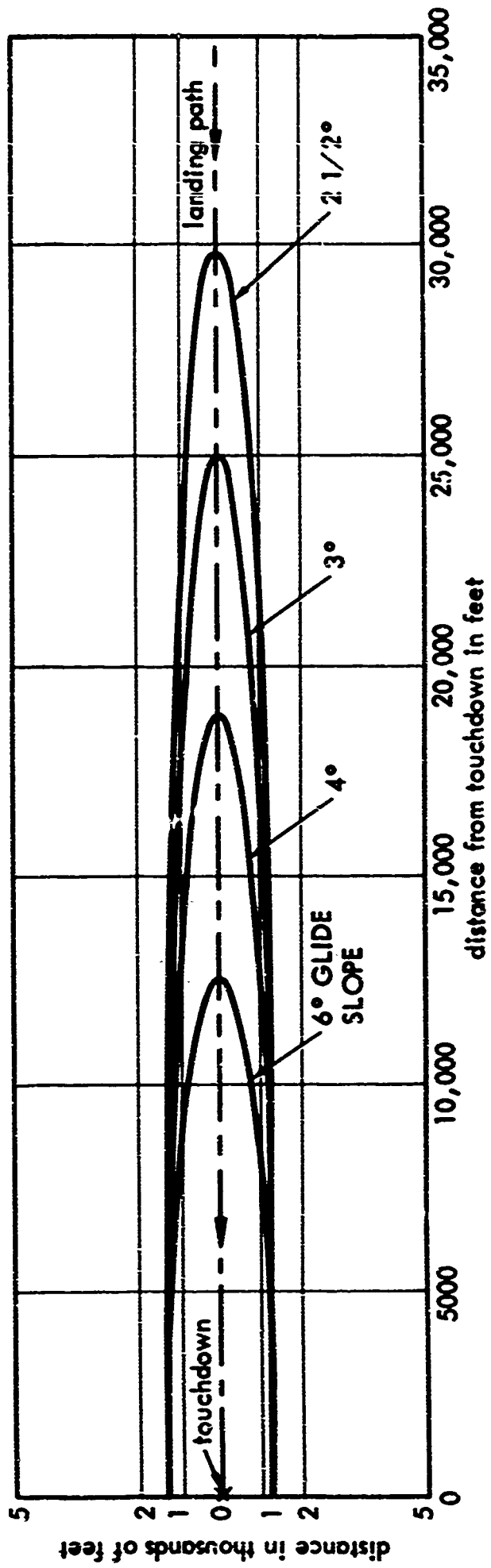
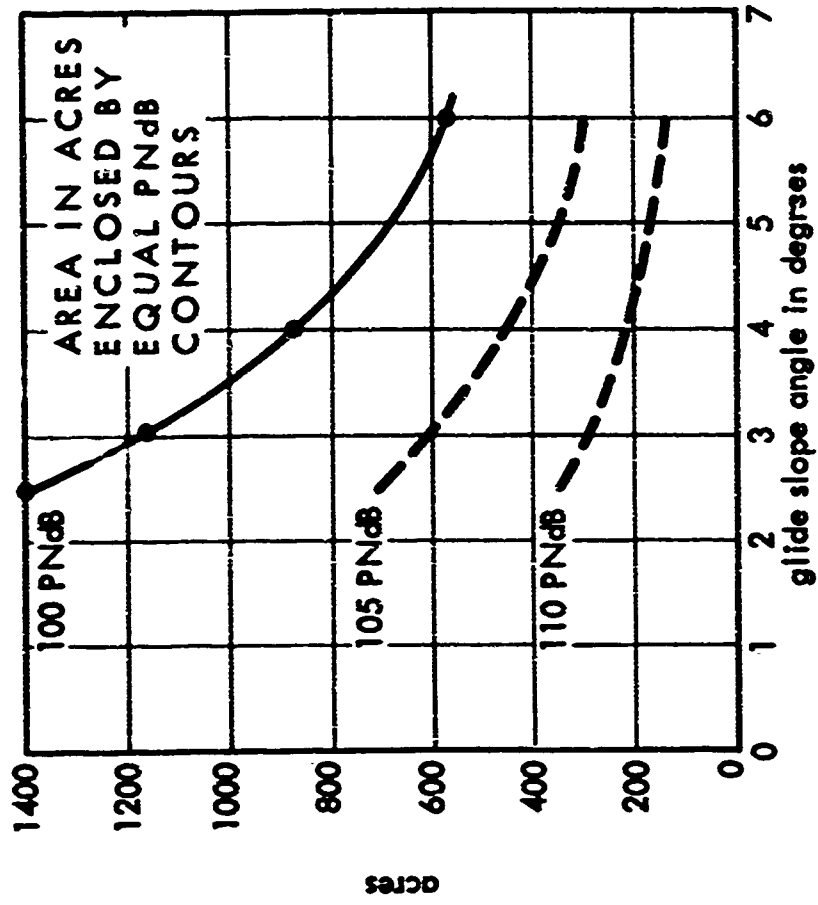


FIGURE 2. VARIATION IN SIZE OF 100 PNdB NOISE CONTOUR FOR DIFFERENT GLIDE SLOPE ANGLES DURING APPROACH OF CONVAIR 990 AT FIXED POWER SETTING OF 4000 LB THRUST PER ENGINE

noise level is also about 4 PNdB. For a change in glide slope from $2\frac{1}{2}^{\circ}$ to 5° , the change in perceived noise level is not as great as for the 990, i.e. about 9 to 13 PNdB in contrast to 10 to 15 PNdB for the Convair 990.

To the side of the landing path the changes in perceived noise level will be less than noted for points directly under the path. This is due to the fact that the relative change in distance to the aircraft is smaller. As an example, for the 990 at 4000 pounds of thrust per engine the change in noise level directly under the approach path for a change in glide angle from 3° to 4° is 4 PNdB at 2 miles from touchdown. At 1000 feet to the side of the landing path the change is only about 1 PNdB.

Another way to show the effect of changing the glide slope angle is by the use of equal perceived-noise-level contours. We have chosen to examine the change in size of the 100-PNdB contour for various glide slope angles. In Fig. 2 the variation in size of the 100-PNdB contour is shown for a 990 on approach at a fixed power setting of 4000 pounds thrust per engine. For these conditions we note that the contour for a $2\frac{1}{2}^{\circ}$ glide slope angle extends almost 30,000 feet from the touchdown point. As the glide slope angle is increased, the length of the contour decreases until, for a 6° glide slope, it extends out approximately 12,500 feet from touchdown.

We have also calculated the area enclosed by the contours shown in Fig. 2. The resulting relationship between area in acres and glide slope angle is plotted in the upper half of Fig. 2. The area enclosed by the 100-PNdB contour for a $2\frac{1}{2}^{\circ}$ glide slope angle is 1400 acres. The area decreases with increasing glide slope angle, until at 6° the area is slightly less than 600 acres, or 40% of the area of the 100-PNdB contour for $2\frac{1}{2}^{\circ}$ glide slope. From the curve in the upper half of Fig. 2 one can also determine the area of the 100-PNdB contour at any glide slope angle between $2\frac{1}{2}^{\circ}$ and 6° . Also shown for comparison are curves (dashed lines) of area-versus-glide slope angle for 105-PNdB and 110 PNdB contours.

In Fig. 3 a similar set of 100-PNdB contours is shown for a 707-120 on approach with a fixed power setting of 6000 pounds of thrust per engine. Here again we note the increase in size of the 100-PNdB contour with decreasing glide slope angles. The 100-PNdB contour for a 6° glide slope extends along the landing path to a distance of approximately 19,000 feet from touchdown. In contrast, the contour for a $2\text{-}1/2^\circ$ glide slope angle extends approximately 45,000 feet from touchdown (off the right hand edge of the graph).*

The area in acres enclosed by the 100-PNdB contours is plotted in the upper half of Fig. 3. At $2\text{-}1/2^\circ$ the area is approximately 3300 acres compared to about 1400 acres for a 6° glide slope. As in the case of the 990, the ratio of the area at 6° to that at $2\text{-}1/2^\circ$ is approximately 40%. For comparison the relationship between area and glide slope angle has been included on this plot for the 105-PNdB and 110-PNdB contours.

One way to summarize the results described in this section is to examine the effect of changing the glide slope

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- * The fact that these contours are somewhat larger in size than the contours shown in Fig. 2 for the 990 is not important in this study. It simply indicates that, at the representative landing thrusts chosen for these two aircraft, the noise output of the 707-120 is greater than the 990. Nor are the perceived noise levels presented for either the 707-120 or the 990 under any condition important per se. What is important are the relative changes in noise exposure for a given aircraft for changes in the quantity under study, such as the glide slope angle.

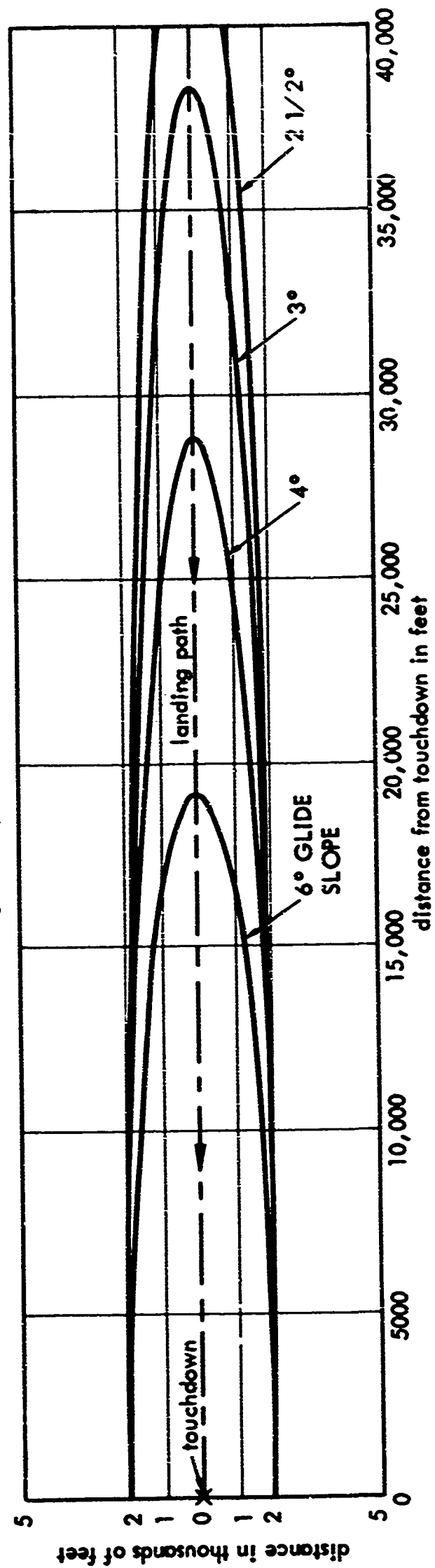
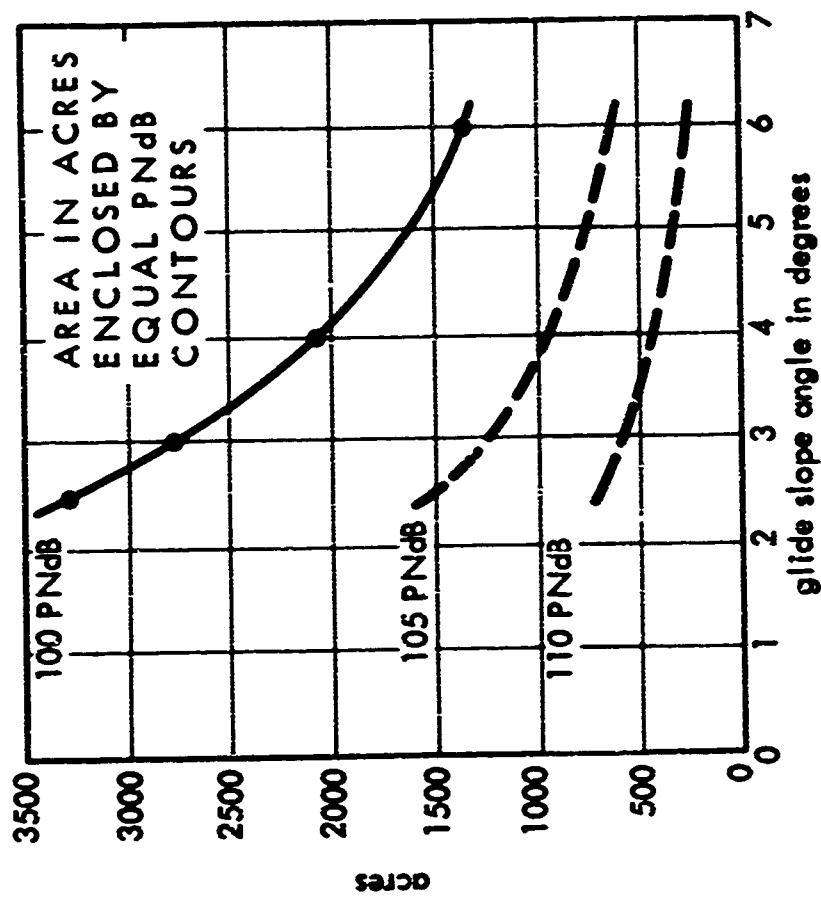


FIGURE 3. VARIATION IN SIZE OF 100 PNdB NOISE CONTOUR FOR DIFFERENT GLIDE SLOPE ANGLES DURING APPROACH OF BOEING 707-120 AT FIXED POWER SETTING OF 6000 LB THRUST PER ENGINE

angle from 3° . The results in terms of PNdB and contour area differences are tabulated below:

Change in Glide Slope Angle	Average Reduc- tion in Perceived Noise Level Directly Under the Path	Per Cent Reduction in Area of 100-PNdB Contours
3° to $3-1/2^{\circ}$	2 PNdB	14%
3° to 4°	4 PNdB	25%
3° to 5°	7 PNdB	40%
3° to 6°	10 PNdB	50%

We see that a change of 3 to $3-1/2^{\circ}$ would effect an average reduction of 2 PNdB under the approach path and a reduction in the area of the 100-PNdB contour of 14%. An additional 2 PNdB reduction could be achieved by raising the glide slope angle to 4° , and another 3 PNdB by raising it to 5° ; the total reduction for a change to 5° would be 10 PNdB. These PNdB differences should be compared with what is required for a noticeable change in the subjective rating of noisiness: 6 PNdB for a 50% change in noisiness, and 10 PNdB for a 100% change in noisiness. Of course, as noted above, the reductions in perceived noise level at points not directly under the approach path will be less than given in the above tabulation.

III. THE EFFECT OF THRESHOLD DISPLACEMENT

Displacement of the threshold has been considered, and in some instances instituted, as a means for reducing the noise under the approach path during landing. Displacing the threshold has the effect of moving the entire glide slope path by the amount of the threshold displacement. This shift in position of the glide slope path means that an aircraft passing overhead will be at a slightly higher altitude along the approach path, and hence will produce a lower perceived noise level on the ground. In this study we have considered threshold displacements of 1000 feet and 2000 feet. The effect of other displacements up to 2000 feet can easily be interpolated from the data presented below.

Figure 4 presents the results of calculations to show the effect of a 1000-ft and 2000-ft threshold displacement on the perceived noise levels produced by a 990 during approach. In this analysis we have assumed a constant glide slope angle of 3° and a constant engine power setting of 4000 pounds thrust per engine. In the figure three landing profiles are shown, the right hand one for a threshold location at the "end of runway,"* the middle one for a threshold displacement of 1000 feet, and the left profile for a threshold displacement of 2000 feet.

The perceived noise levels that would be experienced directly under the approach path for each of the threshold locations are tabulated at the bottom of the graph. It is evident that displacements of the threshold produces only small changes in noise level. For example, for a threshold displacement of 1000 feet, the reduction in perceived noise level varies from $1/2$ PNdB

* The usual location of the threshold is, of course, some distance in from the end of the runway. We have designated the normal location at the "end of the runway" simply for ease of illustration and presentation.

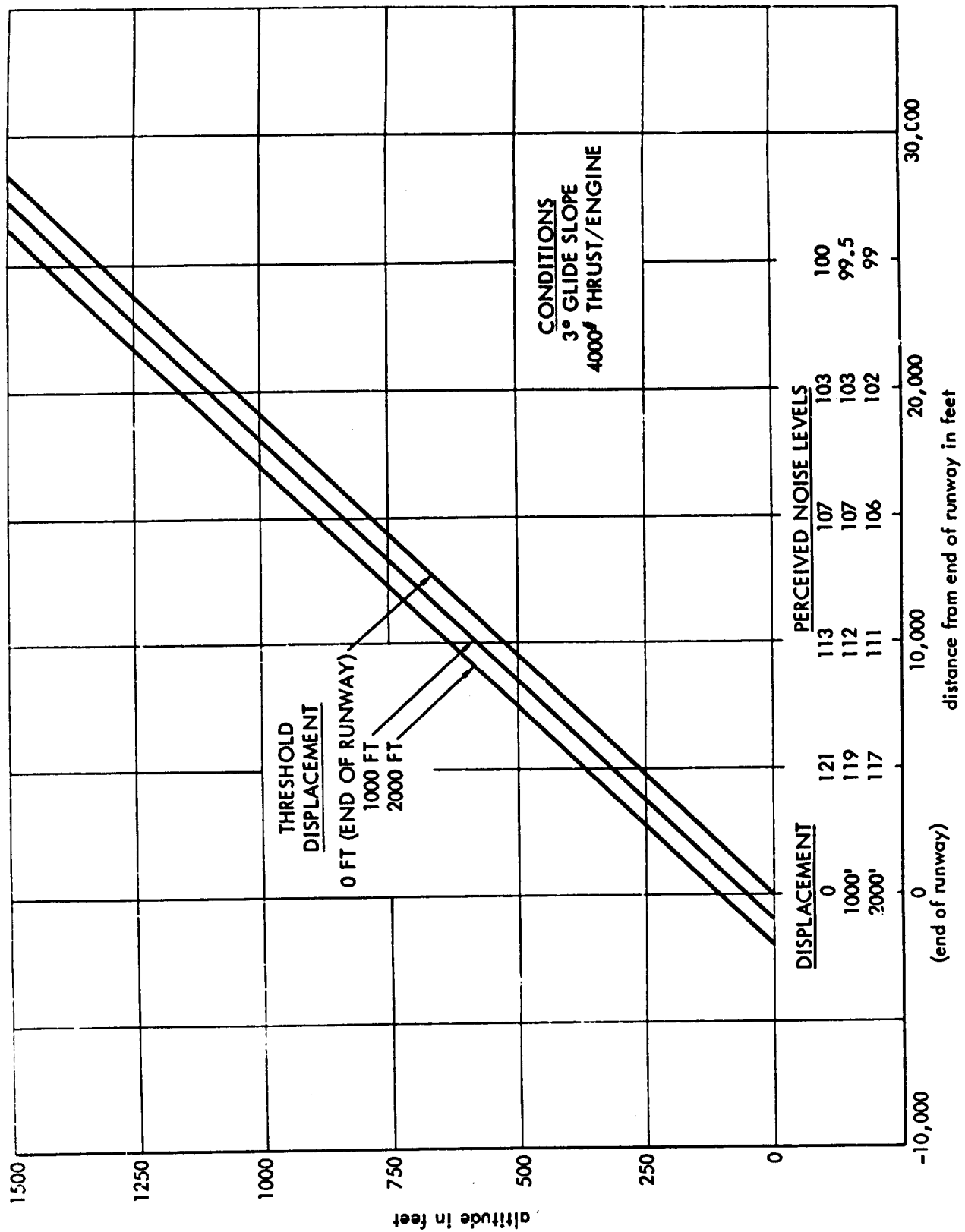


FIGURE 4. EFFECT OF THRESHOLD DISPLACEMENT ON PERCEIVED NOISE LEVELS PRODUCED BY A CONVAIRE 990 DURING APPROACH

at 25,000 feet from the end of the runway to 2 PNdB at 5000 feet. For a threshold displacement of 2000 feet, the change in perceived noise level is greater, but still not appreciable. It varies from 1 PNdB at 25,000 feet from the end of the runway to 4 PNdB at 5,000 feet.

Similar results apply for the 707-120 as shown in Fig. 5. The engine power has been assumed constant at 6,000 pounds of thrust per engine, and the glide slope angle has again been assumed to be 3° . The changes in perceived noise level for the 707-120 are almost exactly the same as those for the 990. At 5000 feet from the end of the runway the changes are 2 PNdB for a threshold displacement of 1000 feet, and 4 PNdB for a displacement of 2000 feet. At 25,000 feet from the end of the runway the changes are $1\frac{1}{2}$ PNdB and 1 PNdB, respectively.

Since the glide slope angle and the engine power have been assumed constant, the only factor affecting the noise level is the change in altitude. Examination of Figs. 4 and 5 shows that the altitude change is the same at all points along the approach path, and is relatively small. For a 1000-ft displacement the altitude is increased by only 50 feet; for a change in threshold of 2000 feet the altitude is increased by 100 feet. The reason that the reduction in perceived noise levels is larger near the runway than farther out along the approach path is that the relative change in altitude is greater near the end of the runway. At 5000 feet from the end of the runway, for example, the altitude increases by 40% -- from 250 feet to 350 feet -- for a 2000-ft displacement. In contrast, at 25,000 feet from the end of the runway, although the absolute change in altitude is the same -- 100 feet, the relative change is much smaller, from 1300 feet to 1400 feet, or about 8%. Hence, the relatively smaller changes in perceived noise level at points farther out under the approach path.

As in the case of a change in glide slope angle, the effect of a displacement in threshold is, of course, most noticeable directly under the approach path since the change in distance to the aircraft is greatest there. To the side of the approach path the noise level changes

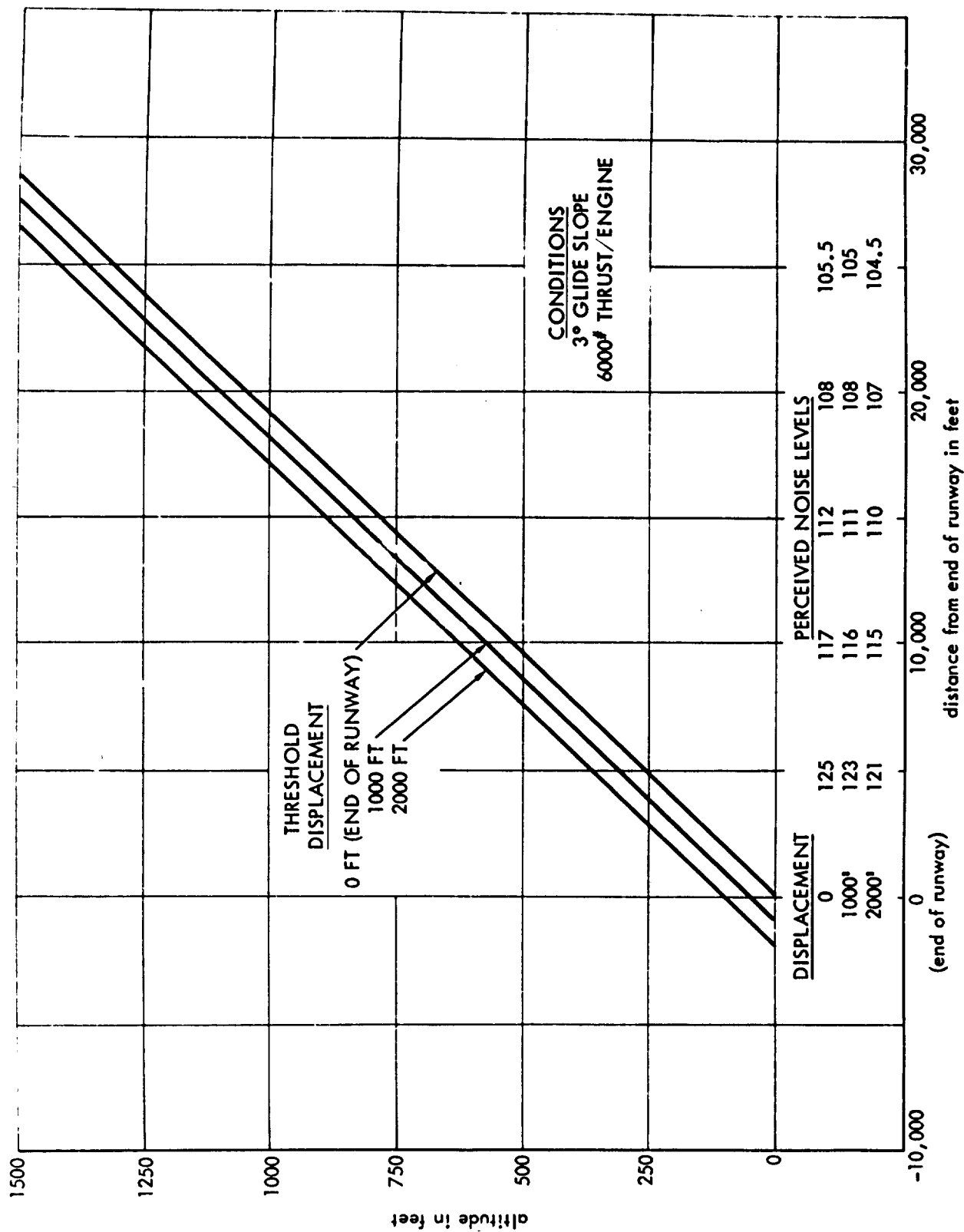


FIGURE 5. EFFECT OF THRESHOLD DISPLACEMENT ON PERCEIVED NOISE LEVELS PRODUCED BY A BOEING 707-120 DURING APPROACH

would therefore be smaller. To illustrate this point we have calculated the change in perceived noise level at two locations to the side of a point underneath the approach path and 10000 feet from the end of the runway for a 990 operating under the conditions shown in Fig. 4. Assuming a threshold displacement of 2000 feet, the change in perceived noise level 500 feet to the side of the path would be 1-1/2 PNdB; 1000 feet to the side of the path it would be 1 PNdB. These values compare with a change of 2 PNdB directly underneath the path.

Although the reduction in noise level that could be effected by displacing the runway threshold is not large in itself, it is important to recognize that it is an additive factor, i.e. independent of a change in glide slope angle or engine power. Whatever reduction could be achieved by raising the glide slope and/or lowering engine power could be enhanced by moving the runway threshold, and the cumulative effect could be quite beneficial.

IV. THE EFFECT OF ENGINE POWER SETTING

There are a number of factors which influence the amount of engine power that is used during the landing of commercial aircraft. Procedures vary among the different airlines as well as among individual pilots. The weather has a bearing on the problem as does the type of jet aircraft being used. Even in good weather an aircraft making an instrument approach on a specified glide slope will employ varying amounts of power depending on whether the aircraft is above or below the glide slope path. The amount of power may also differ depending on the altitude of the aircraft, i.e. how close the aircraft is to the touchdown point.

In this section we describe quantitatively how the perceived noise levels under the approach path are affected by different engine power settings. We have assumed a fixed threshold location - at the "end of the runway," and a constant glide slope path angle of 3° . Further, we have simplified the problem by assuming that a given engine power setting would be held constant during the entire approach from a distance of approximately eight miles from the runway. On this basis we have investigated the changes in perceived noise levels on the ground for four different power settings ranging from approximately 60% thrust downward for both the 990 and the 707-120.

The perceived noise levels experienced directly underneath the landing path during the approach of a 990 operating at four different engine power settings are shown in Fig. 6. The 3° glide slope path shown in the figure gives the aircraft altitude at various points along the landing path. At the bottom of the graph are listed the perceived noise levels in PNdB that would be heard on the ground at 5000-ft intervals along the approach path for 6000 pounds, 4000 pounds, 2500 pounds, and 1500 pounds of thrust per engine.

At 5000 feet from the end of the runway the perceived noise level varies from 125 PNdB for an engine thrust of 6000 pounds per engine down to 112 PNdB for an engine thrust of 1500 pounds per engine. This represents

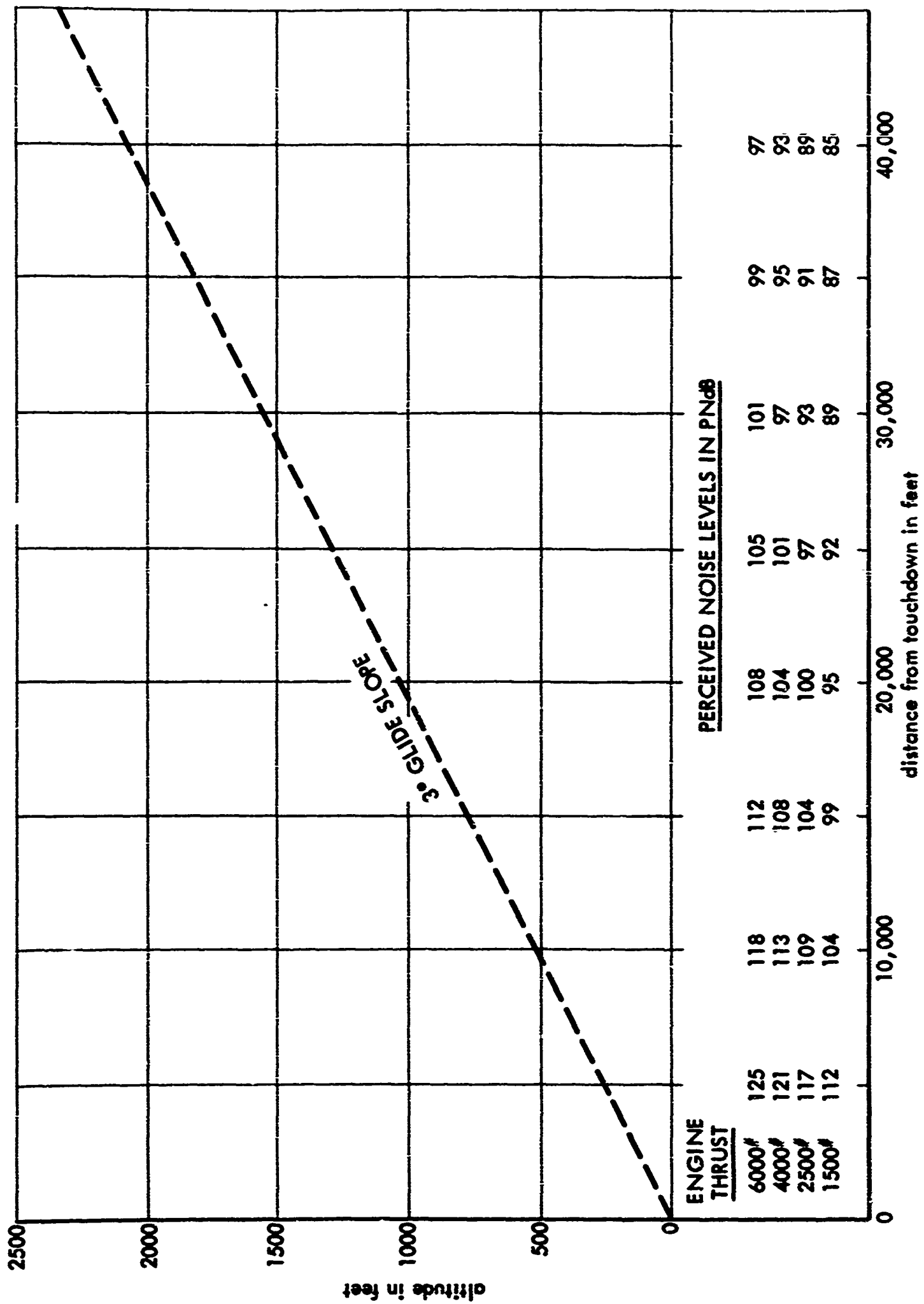


FIGURE 6. COMPARISON OF PERCEIVED NOISE LEVELS UNDER APPROACH PATH FOR CONVAIR 990 OPERATING AT DIFFERENT ENGINE POWER SETTINGS

a difference of 13 PNdB. In a similar manner, changes in PNdB can be determined at other positions directly underneath the flight path. It is interesting to note that the difference in perceived noise levels between any two power settings is approximately the same anywhere underneath the flight path. For a reduction in thrust from 6000 pounds to 4000 pounds the average change is 4 PNdB; from 4000 pounds to 2500 pounds thrust it is 4 PNdB; and from 2500 pounds to 1500 pounds it is 5 PNdB. For a change from 6000 pounds to 1500 pounds thrust per engine the reduction in perceived noise level varies from 12 to 14 PNdB.

Similar information is shown in Fig. 7 for the 707-120 operating at four different engine power settings. Again we see that the differences in PNdB between any two engine power settings are approximately the same along the approach path. Also the actual changes in perceived noise level are approximately the same as those shown on Fig. 6 for the 990. For example, for a change in engine thrust from 8000 pounds per engine (highest) to 3500 pounds per engine (lowest), the change in perceived noise level varies from 11 to 14 PNdB, compared with 12 to 14 PNdB for the 990.

To the side of the landing path the reduction in perceived noise level would be essentially the same as described above for positions directly underneath the landing path. For example, if a change in engine power resulted in a 4 to 5 PNdB reduction under the path, this same reduction would be observed to the side of the path. This result is in contrast to changes in glide slope angle or threshold location where the amount of noise reduction diminishes as one moves farther away from the approach path.

We have also illustrated the effect of changes in engine power setting for each of the two aircraft by means of 100-PNdB contours. In Fig. 8 100-PNdB contours are presented for a 990 approaching at a constant glide slope angle of 3° at four different engine settings. We note that the 100-PNdB contour for a power setting of 1500 pounds thrust per engine extends out to approximately 13,000 feet from touchdown. In contrast the 100-PNdB contour for 6000 pounds thrust per engine extends approximately 32,000 feet from the point of touchdown. Unlike the contours shown in Figs. 2 and 3, illustrating the effect of a change in glide slope angle, these contours

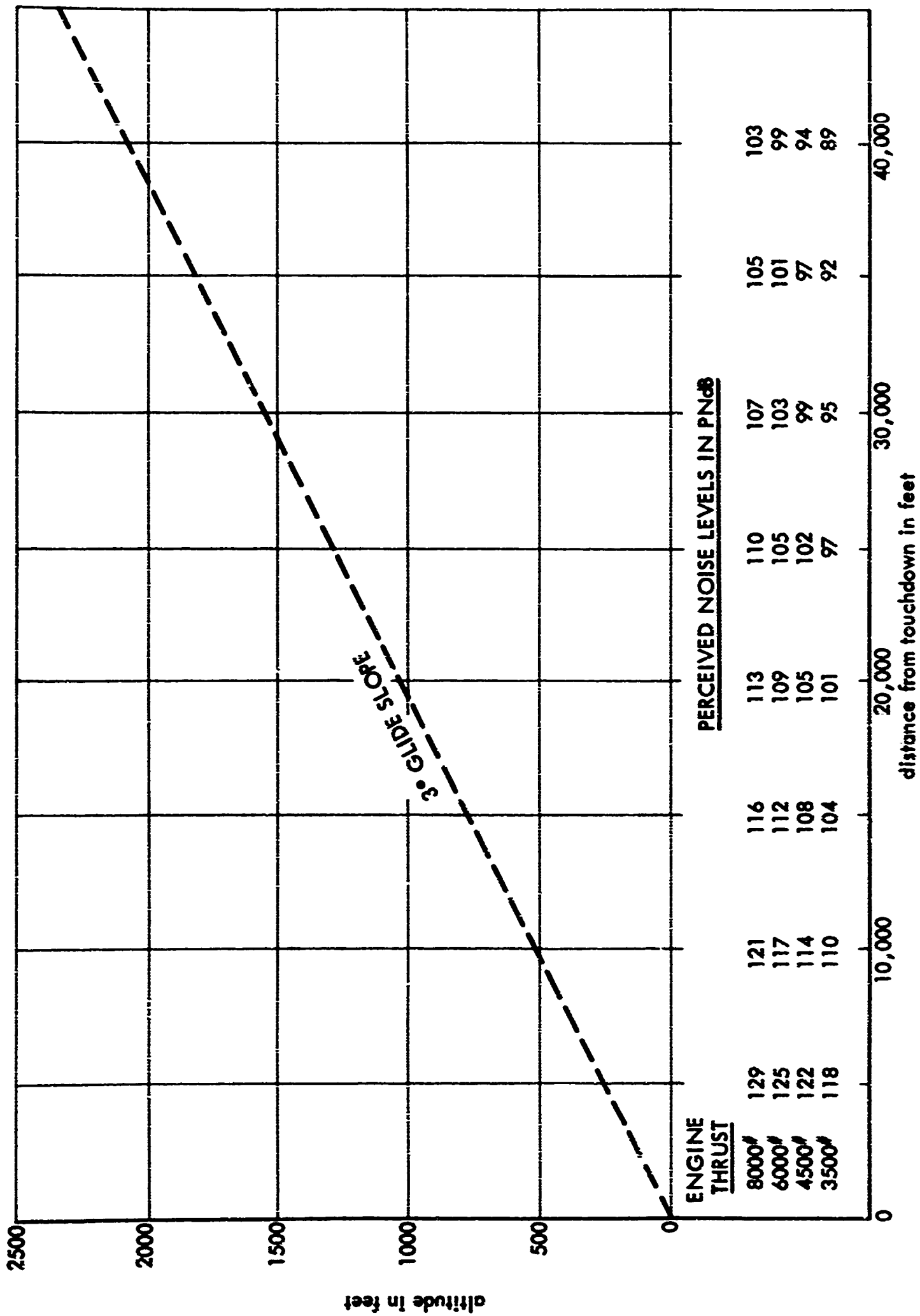


FIGURE 7. COMPARISON OF PERCEIVED NOISE LEVELS UNDER APPROACH PATH FOR BOEING 707-120 OPERATING AT DIFFERENT ENGINE POWER SETTINGS

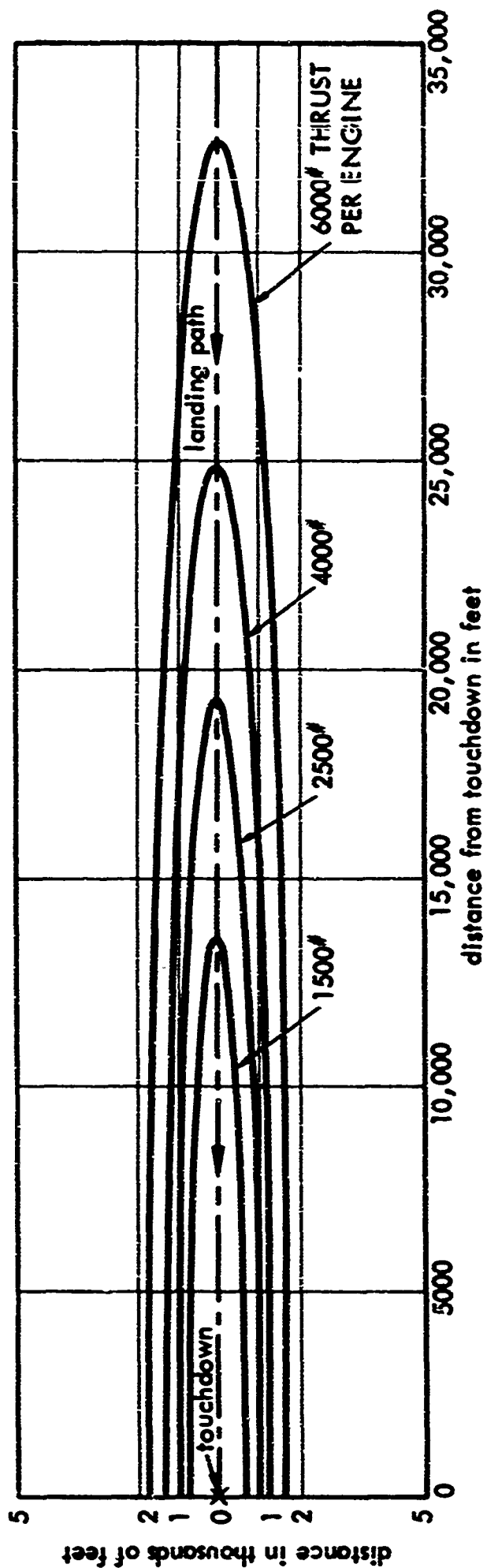
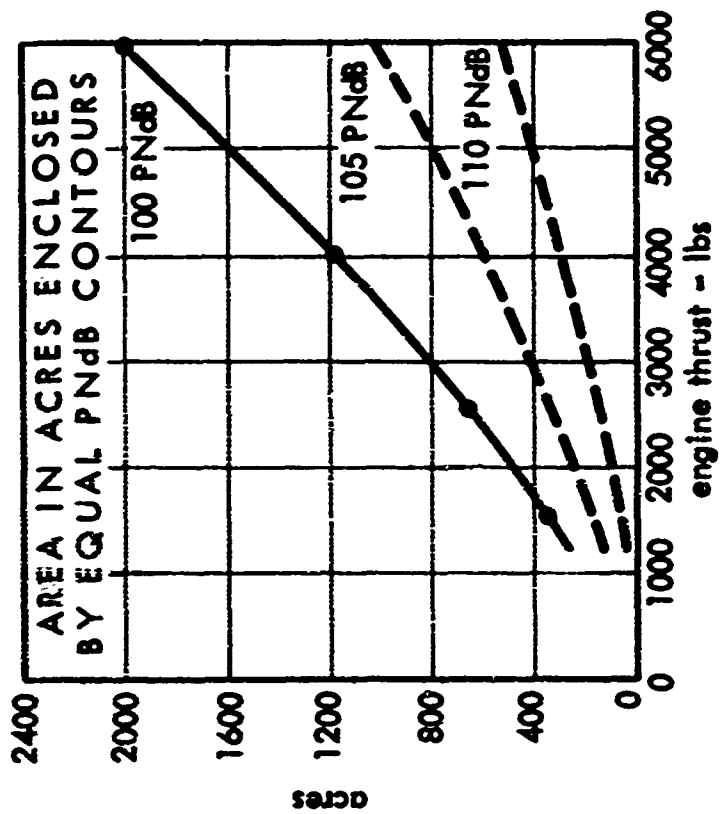


FIGURE 8. VARIATION IN SIZE OF 100 PNdB NOISE CONTOUR FOR DIFFERENT ENGINE POWER SETTINGS DURING CONVAIR 990 APPROACH AT A CONSTANT GLIDE SLOPE ANGLE OF 3°

change not only in length but also in width. Whereas the 100-PNdB contour for a 1500-pound thrust condition extends approximately 700 feet to either side of the landing path, the 100-PNdB contour for a 6000-pound thrust condition extends about 1700 feet either side of the path.

The effect of a change in engine power setting can also be illustrated by comparing the land area enclosed by the 100-PNdB contours. For the four contours shown in Fig. 8 the area in acres has been calculated and plotted versus engine thrust as shown by the solid line in the upper graph in Fig. 8. This plot shows that the area varies from about 350 acres for 1500 pounds thrust to 2000 acres at 6000 pounds thrust. In other words, for a reduction in engine thrust from 6000 pounds per engine to 1500 pounds per engine, the area enclosed by the 100-PNdB contour can be reduced to between 15% and 20% of its former value. Changes in land area for other changes in power setting can be interpolated from the graph.

We have also calculated the area that would be enclosed by the 105-PNdB and 110-PNdB contours. These are described by the dashed lines in the upper graph of Fig. 8. The ratio of the areas at 1500 pounds thrust to those at 6000 pounds thrust is also about 15%.

Figure 9 displays 100-PNdB contours for four engine settings for the 707-120. Again we see, as we did in comparing the noise contours in Figs. 2 and 3 for the glide slope analysis, that the noise contours for the 707-120 are somewhat larger than for the 990. This comparison has no bearing on the problem (see footnote on pg. 10); what is important are the relative changes. In terms of the area enclosed by the contours, the relative changes are about the same. At the high engine thrust, 8000 pounds per engine, the land area within the 100-PNdB contour is a little over 5000 acres. For the low thrust condition the area is about 750 acres, or about 15% of the larger value. This area ratio is essentially the same as for a comparable change in thrust for the Convair 990. Dashed lines showing the variation of area with engine thrust for the 105-PNdB and 110-PNdB contours are also given in Fig. 9.

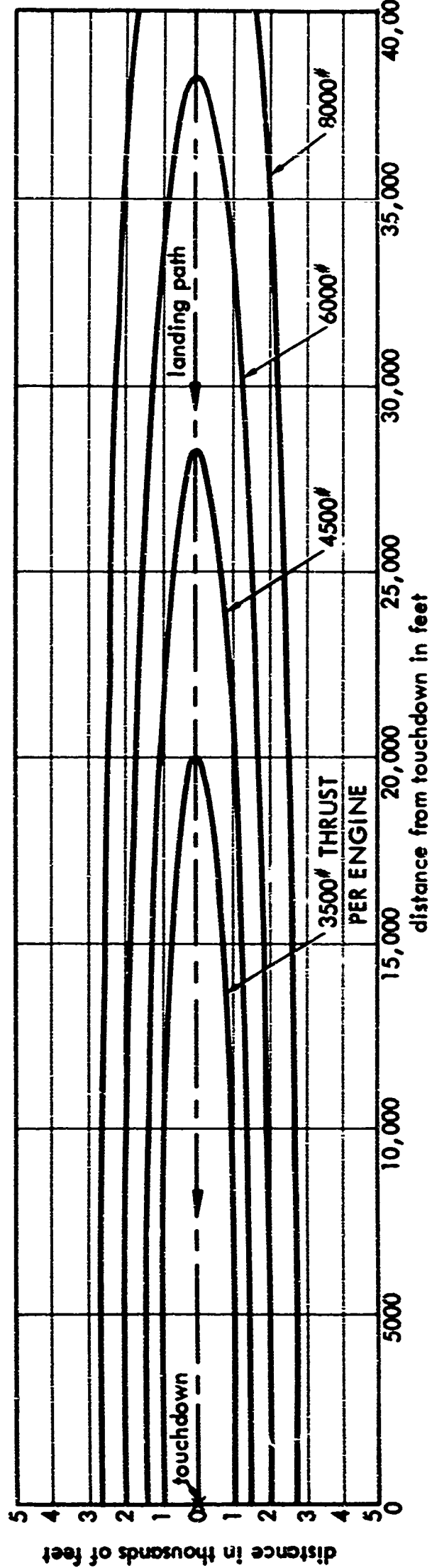
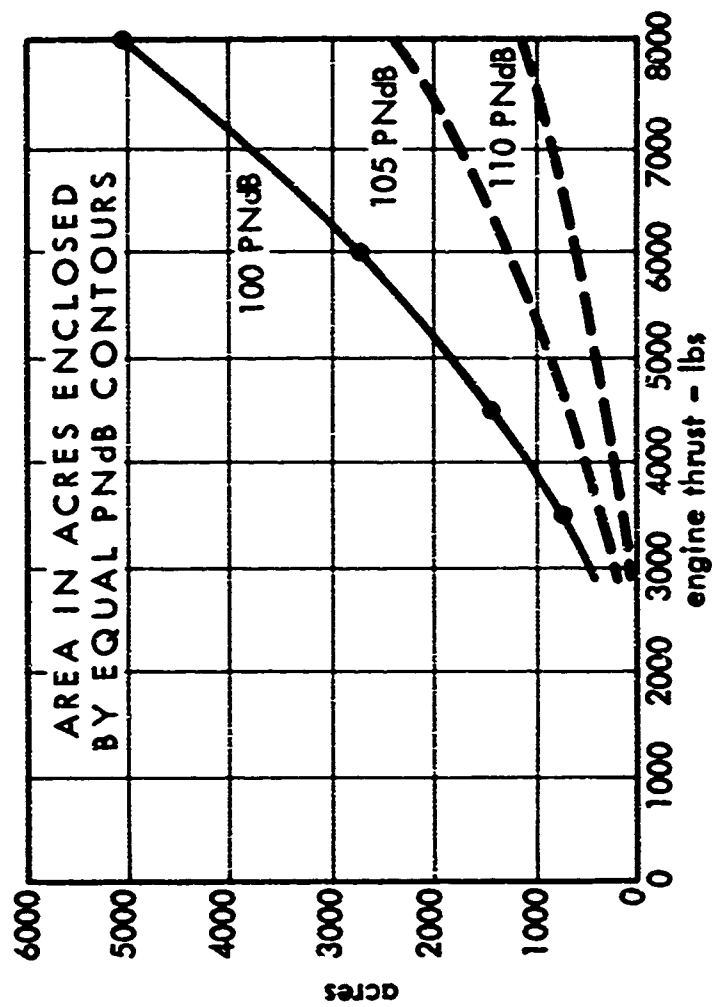


FIGURE 9. VARIATION IN SIZE OF 100 PNdB NOISE CONTOUR FOR DIFFERENT ENGINE POWER SETTINGS DURING BOEING 707-120 APPROACH AT A CONSTANT GLIDE SLOPE ANGLE OF 3°

The engine power settings used in this study for the 990 and the 707-120 are believed to be representative of the range of engine power settings used by each of these aircraft during landing operations. Considering that a change in perceived noise level of 10 PNdB is equivalent to a 200% change in noisiness, and a change of 15 PNdB is equivalent to a 300% change in noisiness, the variation in perceived noise levels over the range of engine power settings discussed here is equivalent to somewhere between a 200% and 300% change in noisiness. This indicates that control of the engine power setting during approach can materially affect the noise exposure on the ground both in terms of the actual perceived noise levels as well as the land area affected.

One might now ask whether these results can be generalized to apply to the other four-engine commercial jet aircraft. Unlike the results discussed in the two earlier sections on the effect of a change in glide slope angle and a displacement of the runway threshold, both of which can be generalized to apply to all commercial jet aircraft flying today almost without reservation, the effects of changes in engine power cannot be readily generalized without reference to the actual noise source characteristics of other jet aircraft at lower power settings. Sufficient data are available in our files on various other jet aircraft, including both turbofan and turbojet aircraft, to permit us to report that the variation in their noise output over comparable ranges of low engine power settings is approximately the same as for the 990 and the 707-120 discussed in detail in this section. Hence, we believe that the results in this section can be generalized to apply to most four-engine jet transport aircraft in operation today.

V. SUMMARY AND CONCLUSIONS

In this report we have shown quantitatively how the noise exposure produced by four-engine jet transport aircraft during landing varies with changes in glide slope angle, runway threshold location, and engine power setting. Calculations have been made for glide slope angles ranging from $2\frac{1}{2}^{\circ}$ to 5° , for runway threshold shifts up to 2000 feet, and for four different power settings from approximately 60% thrust downward for both the Convair 990 and the Boeing 707-120. This range of engine power settings is believed to be representative of that used by these aircraft during landing operations.

Specifically, the major conclusions to be drawn from this study are as follows:

- 1) The relative changes in noise exposure for all three quantities are essentially the same for the turbofan-powered Convair 990 and the turbojet-powered Boeing 707-120 and, on the basis of comparisons with other aircraft noise source data, can be generalized to apply to essentially all four-engine commercial jet airliners in operation in this country.
- 2) The relative importance of the three quantities in order of their potential effect on landing noise exposure is as follows:
 - a) Engine power setting
 - b) Glide slope angle
 - c) Threshold displacement
- 3) For the range of engine power settings believed to be employed in practice during landing, the perceived noise level varies by 11 to 14 PNdB, representative of a change in noisiness of between 200% and 300%. This variation occurs to the side as well as directly underneath the path. The land area enclosed by the 100-PNdB contours varies by a ratio of about six to one over this engine power range.

- 4) For limited changes in glide slope angle, the reduction in noise exposure directly under the approach path is somewhat less, averaging about 2 PNdB for a change in glide slope angle from 3° to $3\frac{1}{2}^{\circ}$, 4 PNdB for a change from 3° to 4° , 7 PNdB for a change from 3° to 5° , and 10 PNdB for a change from 3° to 6° . To the side of the path the reduction would be somewhat less. The corresponding reductions in land area enclosed by the 100-PNdB contour would be 14%, 25%, 40%, and 50%.*
- 5) Displacement of the runway threshold would result in the least change in noise exposure-- about $\frac{1}{2}$ to 2 PNdB for a displacement of 1000 feet, and 1 to 4 PNdB for a displacement of 2000 feet at locations directly under the path. To the side of the path the effect would be less noticeable.

* In practice, changes in glide slope angle would be accompanied by changes in engine power setting. For an increase in glide angle the engine power would generally be reduced. Hence the two changes would be additive; a reduction in noise level would occur for both the increase in glide angle and for the reduced power setting.

REFERENCES

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APPENDIX A

In this appendix we present the noise source data on which the results given in the report are based. Figures A1 and A2 present perceived noise level-versus-distance curves for four different power settings for the Convair 990 and the Boeing 707-120, respectively. These conditions are believed to be representative of the range of engine thrusts used during landing operations. The noise data were obtained basically from References 1 and 2 and were updated on the basis of the revised method for calculating perceived noise level given in Reference 3 and the latest accepted values of attenuation due to air absorption given in Reference 4.

The procedure employed was to take the reference octave band spectra at 1000 feet given in References 1 and 2 and adjust them to apply for various distances from 200 feet to 3000 feet by means of corrections for inverse square attenuation and the attenuation due to air absorption. (A relatively non-directive noise pattern was assumed; i.e. the maximum perceived noise level was assumed to occur as the aircraft passed overhead.) For these derived spectra perceived noise levels were calculated based on Reference 3. These PNdB values were then utilized to plot the smooth curves shown in Figures A1 and A2.

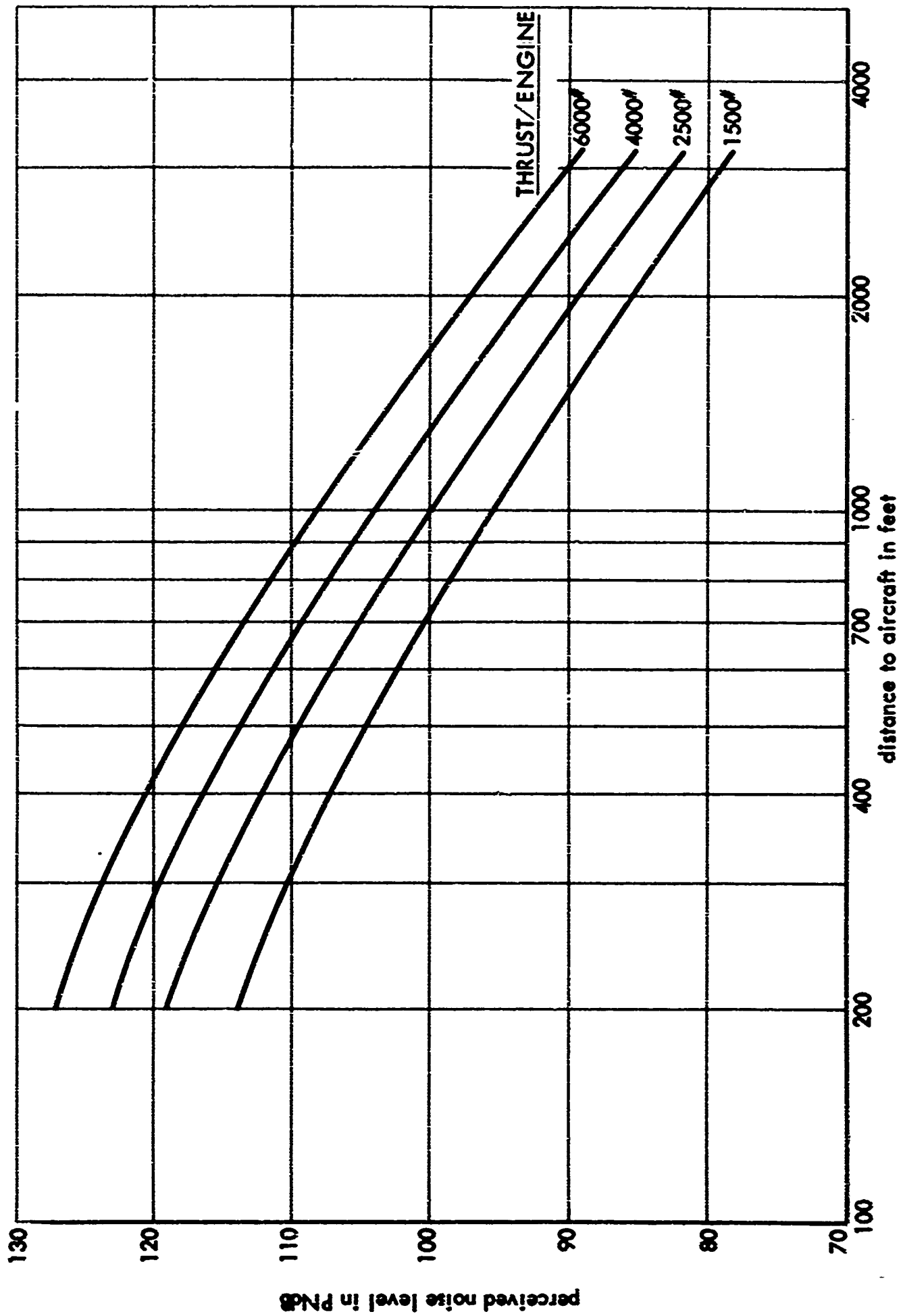


FIGURE A1. PERCEIVED NOISE LEVELS VERSUS DISTANCE
FOR CONVAIR 990 AT DIFFERENT POWER SETTINGS

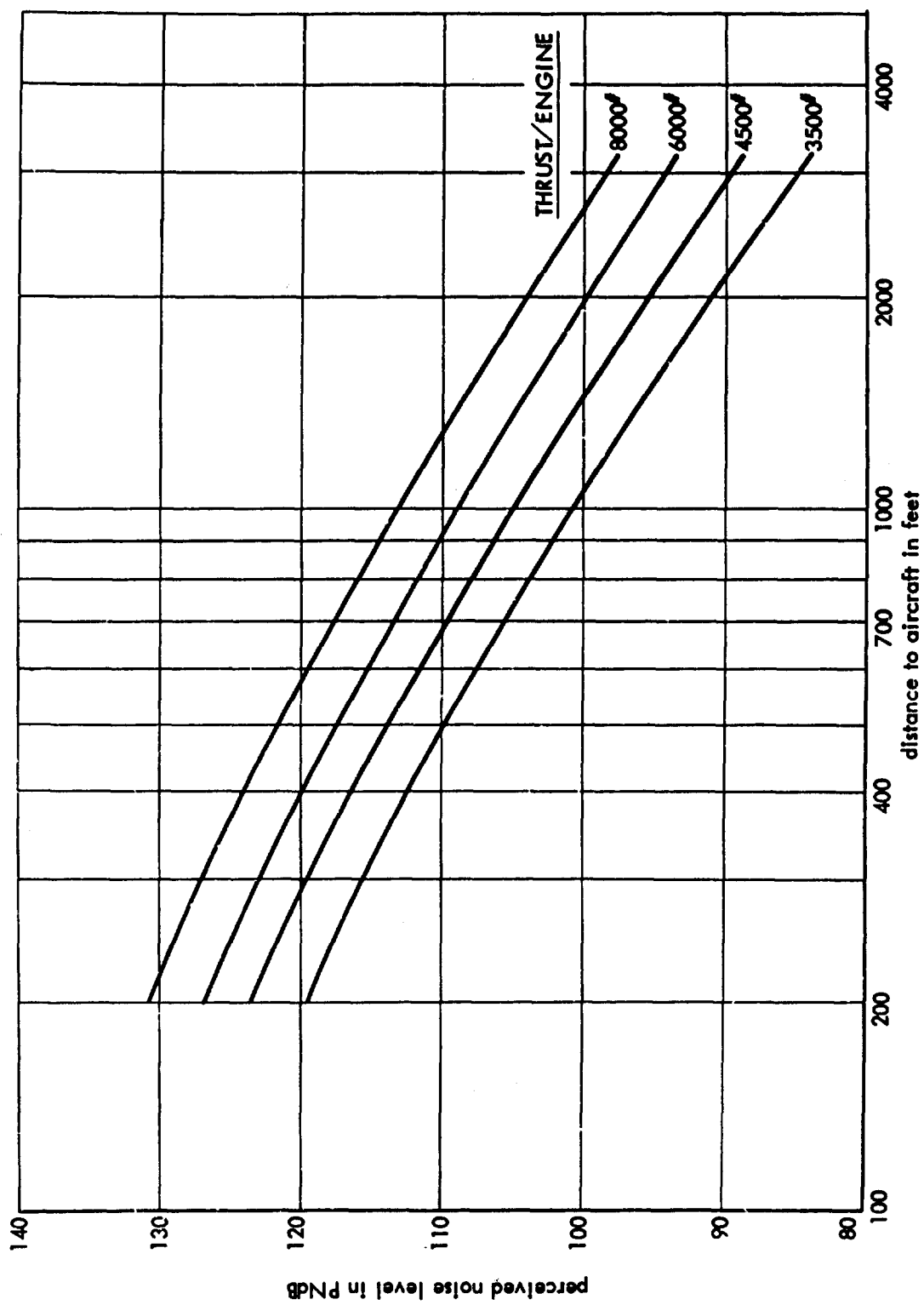


FIGURE A2. PERCEIVED NOISE LEVEL VERSUS DISTANCE
FOR BOEING 707-120 AT DIFFERENT POWER SETTINGS